Reactive Model-based Programming of Embedded Systems

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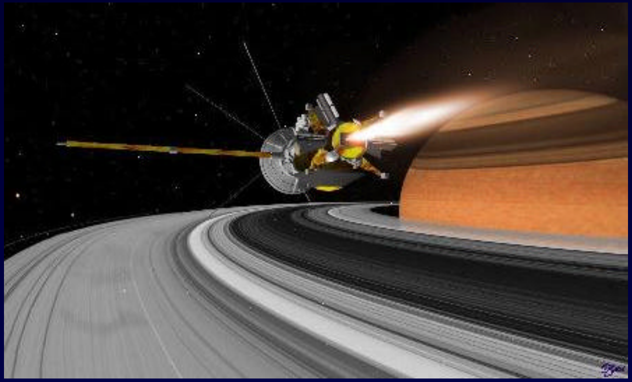
Observations: VLSI circa 1979

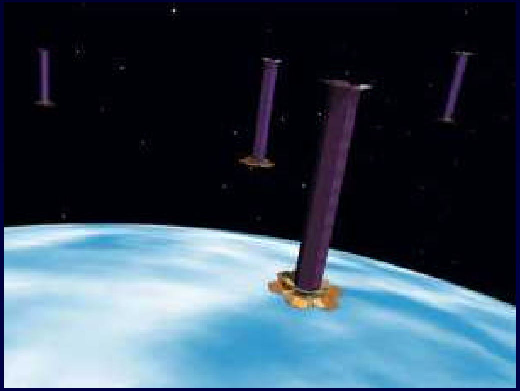
VLSI designers aren’t good at reasoning through complex physical interactions:

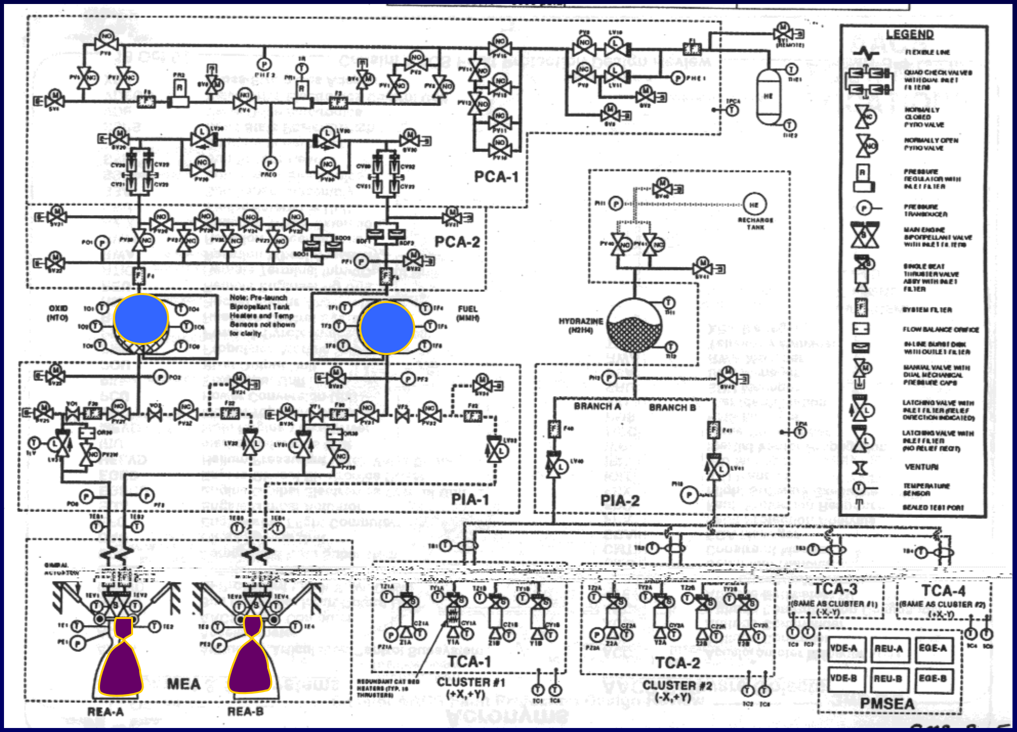
Solution:

- Simplifying abstractions
- Design rules
- Design rule verifiers
- Silicon compilers

Observations: Embedded SW, 2001






PCA-1
PCA-2
OXID (NTO)
Note: Pre-launch Bipropellant Tank Heaters and Temp Sensors not shown for clarity
FUEL (MMH)
HE
HE RECHARGE TANK
HYDRAZINE (N2H4)
BRANCH A
BRANCH B
PIA-1
PIA-2
GIMBAL ACTUATOR
MEA
REA-A
REA-B
REDUNDANT CAT BED HEATERS (TYP. 16 THRUSTERS)
TCA-1
CLUSTER #1 (+X,+Y)
TCA-2
CLUSTER #2 (-X,+Y)
TCA-3 (SAME AS CLUSTER #1) (-X,-Y)
TCA-4 (SAME AS CLUSTER #2) (+X,-Y)
VDE-A
REU-A
EGE-A
VDE-B
REU-B
EGE-B
PMSEA
LEGEND
FLEXIBLE LINE
QUAD CHECK VALVES WITH DUAL INLET FILTERS
NORMALLY CLOSED PYRO VALVE
NORMALLY OPEN PYRO VALVE
PRESSURE REGULATOR WITH INLET FILTER
PRESSURE TRANSDUCER
MAIN ENGINE BIPROPELLANT VALVE WITH INLET FILTERS
SINGLE SEAT THRUSTER VALVE ASSY WITH INLET FILTER
SYSTEM FILTER
FLOW BALANCE ORIFICE
IN-LINE BURST DISK WITH OUTLET FILTER
MANUAL VALVE WITH DUAL MECHANICAL PRESSURE CAPS
LATCHING VALVE WITH INLET FILTER (RELIEF DIRECTION INDICATED)
LATCHING VALVE WITH INLET FILTER (NO RELIEF REQ'D)
VENTURI
TEMPERATURE SENSOR
SEALED TEST PORT

Obs: Embedded Flight Software

Programmers of embedded systems:

- Aren’t good at reasoning through complex physical interactions.
  (Mars Polar Lander, test stand and sw monitor failure).
- Aren’t good at anticipating all novel interactions with the environment.
  (Deep Space One, star tracker).
- Rarely have time to add in fault protection layers.
  (Mars Polar Lander and Climate Orbiters).

➢ Embedded languages should do this for you.

Thesis: Model-based Programming

Embedded programs should:

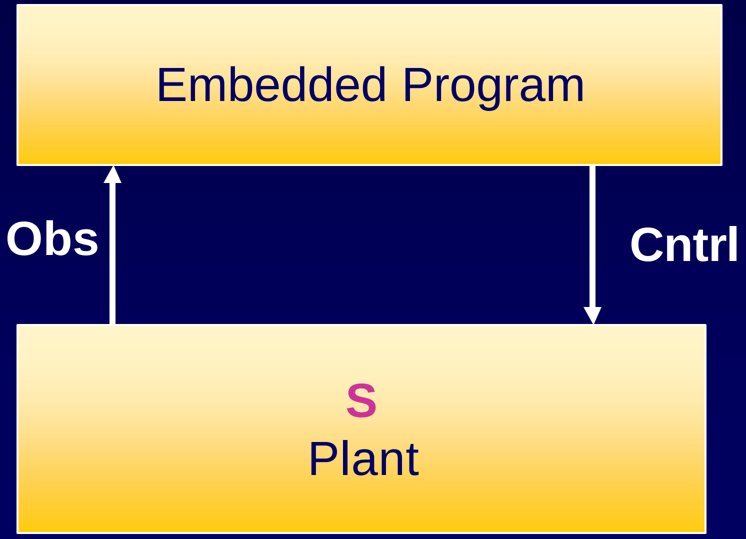
- include models of the physical plant.
- reason through plant interactions for you.
- reveal their reasoning at compile time for analysis.
- reason on the fly to handle unanticipated circumstances.
- reason on the fly to optimize performance to the situation.

⇒ We should fold extensive reasoning into our interpreters and compilers

Reactive Model-based Programming Language, v 1.0

Embedded programs interact with plant sensors and actuators:

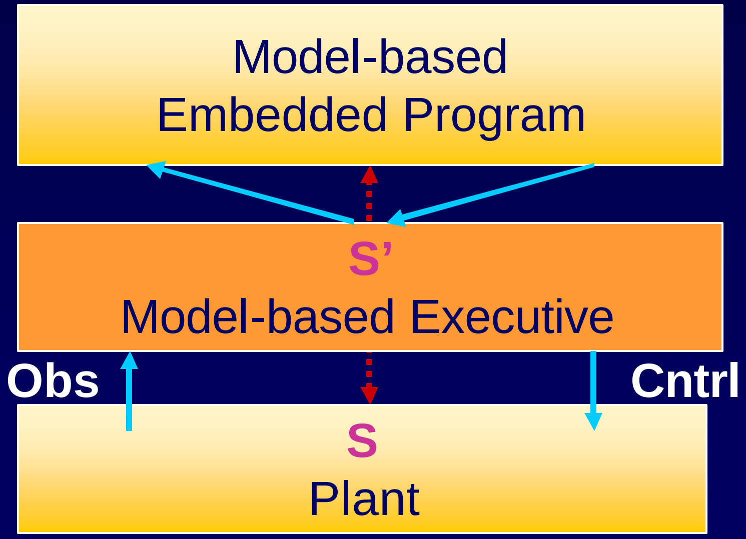
- Read sensors
- Set actuators



Programmer must map between state, sensors, and actuators.

Model-based programs interact with plant state:

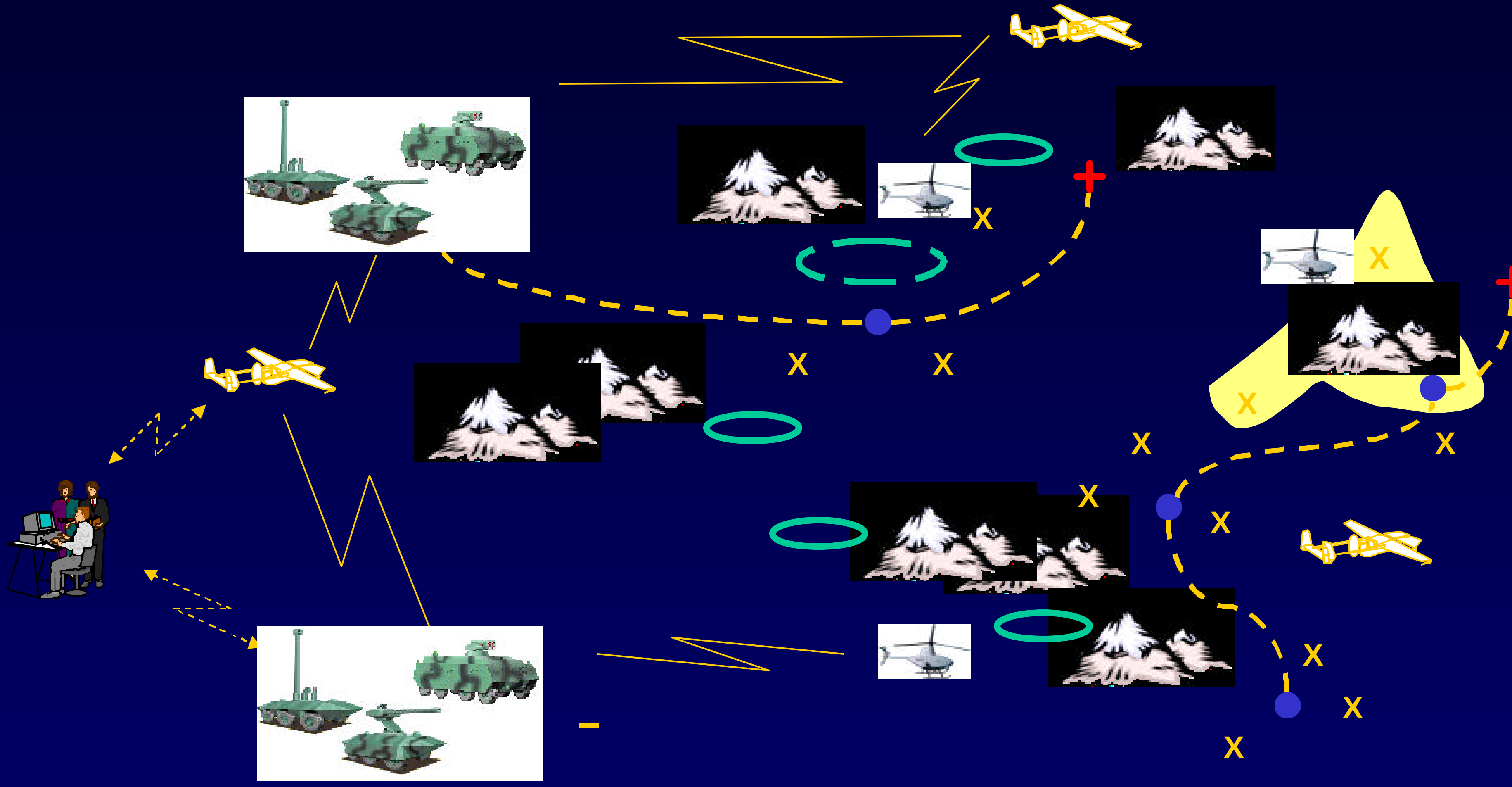
- Read state
- Write state



Model-based executive maps between state and sensors/actuators.

Requires: Propositional SAT engine in reactive loop

DOD: On To Cooperative Systems



+ objective

– – path planned/taken

● identified target

✕ possible target

○ exclusion zones

🟨 exploration region

Reactive Model-based Programming Language, v 2.0

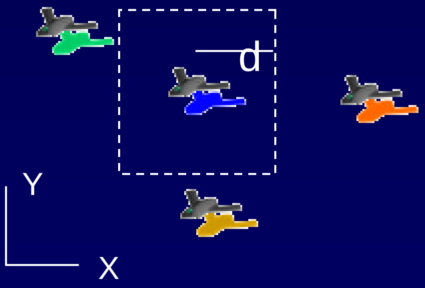
- Cooperative Programs
  - Specify team behaviors as concurrent embedded programs.
  - Introduce redundant options with decision theoretic choice.
  - Introduce timing requirements between activities.

- Model-based Executive
  - Plans and schedules options at the scale of seconds.
  - Continuously searches for optimal plans
  - Monitors execution and replans.

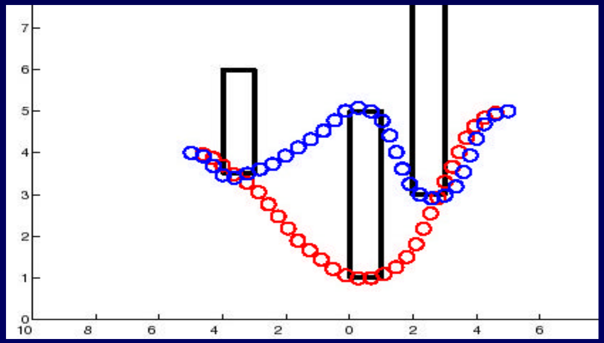
Requires: hierarchical planning and scheduling in reactive loop

Reactive Model-based Programming Language, v 3.0

- Cooperative Programs
  - include goal destinations and flight dynamics
- Model-based Executive
  - plans trajectories and detailed control actions.

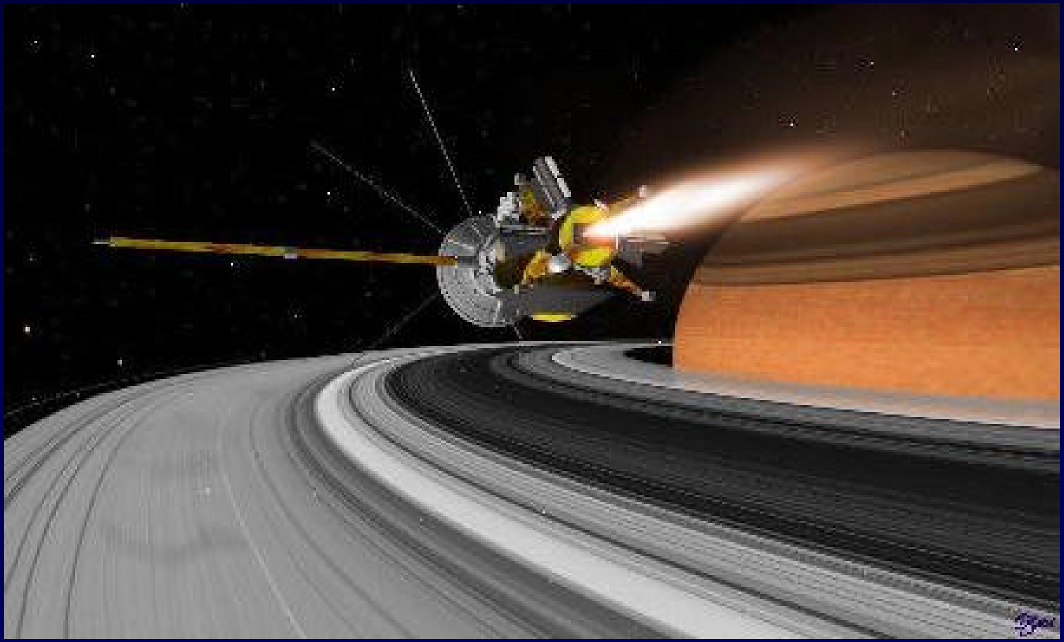


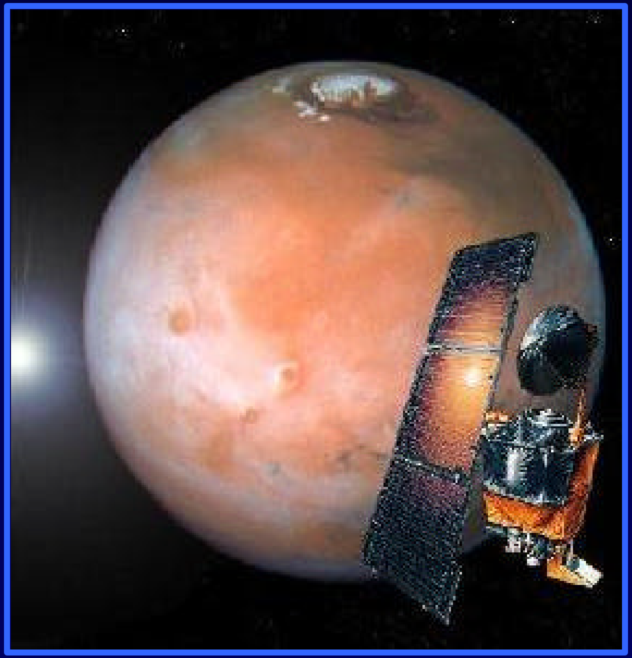
$$
\begin{aligned}
& x_{ip} - x_{iq} \geq d \\
\text{or } & x_{iq} - x_{ip} \geq d \\
\text{or } & y_{ip} - y_{iq} \geq d \\
\text{or } & y_{iq} - y_{ip} \geq d
\end{aligned}
$$



Requires: kino-dynamic path planning and mixed integer/linear programming with in the reactive loop

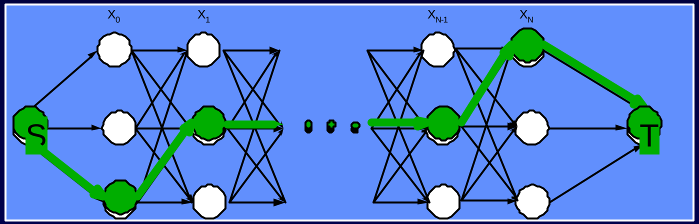
Embedded systems need to anticipate the seemingly unlikely





Reactive Model-based Programming Language, v N.0

- Model-based Programs
  - same as before



- Model-based Executive
  - tracks unlikely system trajectories.
  - extracts statistically significant trends from noise.
  - checks future safety of most likely trajectories.
  - validates plans against likely failures.
  - plans contingencies and prepares for them.

Requires: hybrid mode estimation, model checking, Bayesian inference…with in the reactive loop

Summary: Embedded Flight Software

Programmers of embedded systems:

- Don’t like reasoning through interactions and failure.

➢ Embedded languages should do this for you.

➡ We should fold extensive reasoning into our online interpreters and compilers